a first lens converging the recording light beam
irradiated from the recording laser and directing the
converged recording light beam toward the holographic
recording medium;

5   a second lens converging the alignment light beam
irradiated from the alignment laser and directing the
alignment light beam toward the holographic recording
medium;

a photodetector detecting a light intensity of the
10   alignment light beam reflected from the holographic
recording medium to recognize the alignment mark; and

a driving mechanism adjusting a region to be
irradiated with the recording light beam relative to
the holographic recording medium on the basis of the
15   alignment mark.

According to this invention, there is also
provided a reproducing apparatus for a holographic
recoding medium having an alignment mark and designed
to irradiate a reading light beam onto a recording
20   region of holographic recording medium recorded
information as a hologram to read the information,
the reproducing apparatus comprising:

a reading laser irradiating the reading light beam
for reading the hologram on the holographic recording
25   medium;

an alignment laser irradiating an alignment
light beam onto the holographic recording medium,

the alignment light beam being less absorbed than
the reading light beam by the holographic information
medium, and being reflected by the holographic
recording medium;

5   a first lens converging the reading light beam
irradiated from the reading laser and directing the
converged reading light beam toward the holographic
recording medium;

         a second lens converging the alignment light beam
10   irradiated from the alignment laser and directing the
alignment light beam toward the holographic recording
medium;

         a photodetector detecting a light intensity of the
alignment light beam reflected from the holographic
15   recording medium to recognize the alignment mark; and

         a driving mechanism adjusting a region to be
irradiated with the reading light beam relative to
the holographic recording medium on the basis of
the alignment mark.

20   BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

         FIG. 1 is a diagram schematically illustrating one
example of the construction of the information
recording apparatus according to one embodiment of this
invention;

25   FIGS. 2A to 2C are schematic views, respectively
illustrating the relationship between the direction
of grooves of the recessed/projected surface of the

reflection layer and the irradiation direction of a recording beam;

FIG. 3 is a graph wherein the changes of the absorption coefficient and refractive index are expressed as a function of the wavelength;

FIG. 4 is a diagram schematically illustrating another example of the construction of an information recording apparatus according to one embodiment of this invention;

FIGS. 5A and 5B respectively show schematic views illustrating the construction of a three-dimensional optical recording medium that has been manufactured in one example of this invention;

FIG. 6 is a diagram illustrating an interference fringe formed between a signal beam and a reference beam;

FIG. 7 is a perspective view illustrating the alignment means of information recording apparatus according to one example of this invention; and

FIG. 8 is a perspective view illustrating the alignment means of information recording apparatus according to one example of this invention.

DETAILED DESCRIPTION OF THE INVENTION

Next, this invention will be explained with reference to the following examples.

A holographic recording medium, i.e. a three-dimensional optical recording medium which represents

one example of the recording apparatus of this
invention and is designed to record information in
a form of hologram is provided with a recording layer
containing at least a material whose refractive index
or absorptivity coefficient can be modulated by the
irradiation of a light beam. This recording medium
may be constructed according to any kind of technique
as long as it is provided with a recording layer
containing a material whose refractive index or
absorption coefficient can be modulated spatially by
the irradiation of a light beam.

For example, it is possible to employ a
photorefractive medium provided with a recording layer
containing a photorefractive material whose refractive
index can be modulated by an internal electric field
generated by the redistribution of photo-generated
carriers, or a photopolymer medium provided with
a recording layer containing a photopolymer material
whose refractive index or absorption coefficient can
be modulated by an intermolecular reaction or by
a reaction inside a molecule due to the irradiation
of a light beam.

In particular, the photorefractive medium should
preferably be selected from those which make it
possible to erase data. Since the photorefractive
material is excellent in permeability, a hologram can
be stored throughout the entire body of the recording

layer. As for specific examples of the photorefractive material, it is possible employ any kind of material as long as it is provided with the aforementioned features. For example, it is possible to employ

5   a material containing fullerene such as C_{60}, a phthalocyanine compound, an azo compound, a pyrazoline compound or a naphthalocyanine compound.

Preferably, this recording layer should be constructed such that the material whose refractive

10   index can be modulated by the irradiation of a light beam is dispersed in a matrix material comprising of a transparent polymer such as polystyrene, PMMA, etc.

The three-dimensional optical recording medium for performing the recording and reading of data, which can

15   be employed in the apparatus according to one example of this invention has an alignment mark and may be constructed such that it is provided with a recessed/ projected surface corresponding to the configuration of the track of the recording region. The recessed/

20   projected surface may function as the alignment mark. The three-dimensional optical recording medium in this case is provided with a reflective layer having a recessed/projected surface. This reflective layer is designed that the recording light beam can be prevented

25   from being reflected, thereby allowing only the alignment light beam to be reflected. Generally, the width of this recessed/projected portion may be about

1000 nm and the depth thereof may be about 150 nm.

Next, the information recording apparatus according to one example of this invention will be explained.

FIG. 1 schematically illustrates one example of the construction of an information recording apparatus according to one embodiment of this invention.

The light beam emitted from a recording light source 1 is split by suitable means for splitting a light beam such as a beam splitter 2. The light beams split in this manner are allowed to pass via mirrors 3 and 4, and via objective lens 11 and 12 to the recording region 13 of the optical recording medium 16 as shown in FIG. 1, thus irradiating the recording region 13.

The diameter of the light beam emitted from the light source 1 can be expanded by suitable means such as a beam splitter before passing through the objective lens 11 and 12.

For the purpose of modulating the spatial intensity, phase or polarization of a light beam, or any combination thereof, a spatial modulator 10 is disposed on the optical path of one of the split light beams. On the other hand, the light beam emitted from an alignment light source 21 is converged, after passing through a beam splitter 23 and an objective lens 24, onto an optical recording medium 16 as shown

in FIG. 1.

In the apparatus shown in FIG. 1, the wavelength
of the recording light beam should preferably be
shorter than the wavelength of the alignment light

5   beam. It becomes possible, through the selection of
a wavelength in this manner, to enhance the carrier-
generating efficiency by the recording light beam,
thereby making it possible to shorten the recording
time. Additionally, the absorption of an alignment

10   light beam can be minimized, thereby making it possible
to minimize the generation of noise in the alignment
signal, because it makes little changes to the
recording layer. Generally, organic substances
strongly absorbs light having a wavelength of about

15   400 nm. Therefore, in order to enable the light beam
to reach to the interior of medium without being
absorbed, a light having a wavelength which is slightly
longer than the wavelength that will be strongly
absorbed is employed as a recording light beam.

20   The absorption of the wavelength of the alignment light
beam by the medium is smaller then the absorption of
the wavelength of the recording light beam. In other
words, the medium absorbs the wavelength of the
recording light beam than that of the alignment light

25   beam.

The light source useful in this case should
preferable be a semiconductor laser. In particular,

it is preferable to employ, as the alignment light

source 21, a red light having a wavelength of 635 nm or

650 nm, which is usually employed in the DVD. As for

the light source for recording a hologram, it is

5   required to employ a coherent light source. Therefore,

when a semiconductor laser is employed, the semicon-

ductor laser should preferably be combined with an

external resonator. It is also possible to employ,

as a recording light beam, a second harmonic generated

10   by an optical guide path. Though it may depend on

the kind of recording medium, the wavelength of the

recording light beam should preferably be in the range

of 400 nm to 650 nm so as to enable the recording

medium to suitably absorb the recording light beam.

15   More preferably, the wavelength of the recording light

beam should be in the range of 400 nm to 550 nm.

Incidentally, the optical recording medium shown

in FIG. 1 may be provided thereon with a recessed/

projecting reflective layer (not shown). This

20   reflective layer is designed such that among the light

beam irradiated onto the optical recording medium 16,

only the recording light beam is permitted to pass

therethrough, but the alignment light beam is reflected

by the reflective layer. The alignment light beam

25   reflected in this manner is permitted again to pass

through the objective lens 24 as shown in FIG. 1.

The light beam passed through the objective lens 24 is

then introduced via a beam splitter 23 into a split
beam detector 25. The intensity of the beam obtained
by the split beam detector 25 is calculated by any of
the following methods so as to obtain an alignment
5   signal consisting of a tracking signal and a focusing
signal.

As for the tracking optical system, it is possible
to employ various known methods such as a non-focusing
method, Foucaut method, a spot size method, etc.
10   On the other hand, as for the focusing optical system,
it is possible to employ various methods such as a
3-beam method, a push-pull method, wobbling method,
etc.

Although not shown, in order to full use of the
15   power of the alignment laser 21, a polarized beam
splitter can be used as the beam splitter 23. In this
case, a proper retardation plate, a $\lambda/4$ plate when
linearly polarized light source is used as a laser 21,
should be placed between the beam splitter 23 and the
20   optical recording medium.

In this case however, it is taken as a matter of
course that a difference between the position where the
alignment light beam emitted from the alignment light
beam source is to be converged as well as the position
25   where the recording light beam is to be converged is
already known, so that by measuring the deviation
of the alignment light beam, the deviation of the

recording light beam can be detected.

On the other hand, when it is desired to reproduce the recorded information, a readout light beam 12 is irradiated onto the recording region 13 so as to obtain a diffracted light beam. This diffracted light beam is then collimated by a lens 14, after which the collimated light beam is detected using a split detector 15 such as a CCD. The position of the objective lens 14 can be adjusted as follows. Namely, the position of objective lens 14 is adjusted in such a manner that the light beam that has passed through the objective lens 14 after passing through a spatial modulator 10, through an objective lens 11 and through the optical recording medium 16 becomes a parallel light beam having a distribution which is analogous with the spatial distribution of the light beam exhibited before it was passed through the objective lens 11. This can be realized by the following arrangement. Namely, the distance between the objective lens 14 and the objective lens 11 is made identical with the sum of the focal lengths of the lens 11 and lens 14. The distance between the spatial modulator 10 and the objective lens is made identical with the focal length of lens 11. Further, the distance between the objective lens 14 and the split detector 15 is made identical with the focal length of the lens 14. Although the optical recording medium 16

can be disposed at any optional position between the
lens 11 and the lens 14, the optical recording medium
16 should preferably be disposed close to the focal
point of the lens 11.

5   It is possible in the information recording
apparatus constructed as shown in FIG. 1 to reproduce
the recorded information having a high SN ratio by the
irradiation of a readout light beam.

It is preferable in the information recording
10   apparatus constructed as shown in FIG. 1 that the
recording light beam is irradiated parallel with the
direction of the track of the three-dimensional optical
recording medium.

In this case, the interference fringe to be
15   generated due to the recording light beam may be
extended in the direction perpendicular to the
direction of track (the lateral direction of track),
but would not be extended in the direction of track.
Therefore, even if the alignment light beam is
20   diffracted by this interference fringe, the direction
of the diffraction would become such that it extends
along the direction of track. As a result, the
alignment light beam would deviate in the direction of
track, so that the adjustment of alignment can be
25   accomplished by simply performing a minute adjustment
in the direction of track.

Next, the relationship between the direction of

groove of the recessed/projected surface of reflection layer and the irradiation direction of the recording light beam will be explained with reference to FIGS. 2A to 2C. FIG. 2A shows a birds-eye view illustrating

5   the relationship between the groove of the recessed/ projected surface of reflection layer and the recording light beam that has been split into two. FIG. 2B shows a cross-sectional view which is perpendicular to the groove of the recessed/projected surface of reflection

10   layer. FIG. 2C shows a cross-sectional view which is parallel with the groove of the recessed/projected surface of reflection layer.

As shown in FIG. 2A, the split recording light beams 101 and 102 will be irradiated onto the recording

15   layer 104 of the three-dimensional optical recording medium (disk) 100. One of these beams is a signal light beam bearing information, while the other is a reference light beam. The light beams 101 and 102 are subsequently intersected with each other in the

20   recording layer, thereby forming an interference fringe 107 and making it possible to perform the recording of information. As shown in FIG. 2A, the medium (disk) 100 is designed to be rotated in the direction of 108, and the recording layer 104 of the medium 100 is

25   designed to be irradiated with the alignment light beam 106 at first, which is followed by a simultaneous irradiation of the recording light beams 101 and 102.

The order of irradiating light beams should preferably be such as described above in view of the alignment, but this order may be reversed.

As shown in FIGS. 2B and 2C, the optical recording medium to be irradiated with a signal light beam and a reference light beam is provided on the reflective layer 105 thereof with a recording layer 104 and a protective layer 103, which are successively deposited in the mentioned order.

The reflective layer 105 may be formed of a substrate or a layer, each having a recessed/projected surface. Alternatively, this reflective layer 105 may be a film which is formed along a recessed/projected surface of a supporting substrate or of a supporting layer. The recessed/projected surface of this reflective layer is designed such that the light beam reflected from this layer is the largest when it is properly positioned. When the light beam is designed to be positioned on the recessed portion but is not properly positioned, a part of the beam is reflected from the projected portion and reduces the total intensity of the reflected beam because of the interference when the depth of the recessed/projected surfaces is $\lambda_2/4$, where λ_2 is the wavelength of the alignment light beam.

A deviation of position along the track can be corrected by adjusting the timing of reading data.

For the purpose of minimizing the deviation in the direction perpendicular to the track as mentioned above, it is preferable to record an interference fringe 107 in the direction perpendicular to the track to thereby minimize the diffraction in the direction perpendicular to the track.

In the information recording apparatus according to one example of this invention, the alignment light beam should preferably have little interaction with the recorded grating. More precisely the diffraction of the alignment light beam by the recorded grating should be negligible. The wavelength of light to be emitted from the alignment light beam source should preferably be one where a change in absorption coefficient of the recording layer of the three-dimensional optical recording medium becomes substantially maximum after the recording of hologram.

FIG. 3 is a graph wherein the changes ($\Delta \alpha$) of the absorption coefficient and the changes (Δn) of the refractive index of the three-dimensional optical recording medium, both changes being brought about due to the generation of an internal electric field, are expressed respectively as a function of wavelength. In FIG. 3, the curve "a" represents the changes ($\Delta \alpha$) of the absorption coefficient, while the curve "b" represents the changes (Δn) of the refractive index. Since the diffraction efficiency is influenced much

more by the change of the refractive index than the
change of the absorption coefficient, it is preferable
to employ, as the recording light beam, a wavelength in
the vicinity of the wavelength λ_1, and to employ, as

5   the alignment light beam, a wavelength in the vicinity
of the wavelength λ_2.

The wavelength which does not cause a substantial
change in the refractive index of the recording layer
before and after the recording of a hologram can be

10   measured as explained below.

First of all, by using an objective lens, a white
light beam from a mercury lamp is converged in the
vicinity of the refractive index-modulating region.
On this occasion, the spot size should preferably be as

15   small as possible. Further, in order to prevent the
refractive index-modulating region from being erased
due to the irradiation of the white light beam, the
intensity of white light beam should be sufficiently
minimized.

20   The light beam that has passed through the
refractive index-modulating region is permitted to
enter into a monochromator so as to sorten the
wavelength. Then, the intensity of the light beam
is measured as a function of wavelength by a photo

25   multiplier. Thereafter, the ratio between the value
thus obtained and the value that has been measured in
the same manner before the recording of information is

calculated as a common logarithm, thereby making it possible to measure a difference in absorption spectrum before and after the recording. Further, by the relationship of Kramers-Kronig, the difference spectrum of the refractive index is calculated from that of absorption coefficient.

Incidentally, the wavelength λ_2 at which there is no change of refractive index before and after the recording of a hologram in the optical recording medium will fluctuate depending not only on the kind of material whose refractive index can be modulated by the irradiation of a light beam, but also on the chromophore of the molecule used or quantity of material to be contained in the medium. In other words, the wavelength λ_2 can be adjusted through the control of these conditions so as to make it identical with the wavelength of the alignment light beam.

Further, in the information recording apparatus according to one example of this invention, a light beam emitted from the recording light beam source is split into two beams, i.e. a signal light beam and a reference light beam, which should preferably be irradiated onto a three-dimensional optical recording medium at an incident angle which makes the alignment light beam impossible to generate a primary diffractive light beam that may be caused due to the interference fringe recorded by these recording light beams.

The details related to this feature will be explained hereinafter. When the light beams, i.e. a signal light beam and a reference light beam are irradiated at such an incident angle, it becomes possible to prevent the alignment light beam from being diffracted even if a hologram has been recorded in the medium.

It is preferable in the information recording apparatus of this invention that the objective lens for converging the alignment light beam emitted from the alignment light beam source is formed integral with the objective lens for converging the reference light beam emitted from the recording light beam source. It is better that the objective lens for converging the alignment light beam emitted from the alignment light source is formed integral with the objective lenses for the signal and reference beams emitted from the recording light beam source.

FIG. 4 schematically illustrates one example of the construction of an information recording apparatus having an integrated converging means. As shown in FIG. 4, the light beam emitted from a recording light beam source 110 is split into two by means 111 which is designed to split the recording light beam. One of the light beams is transmitted via means 114 which is designed to converge the recording light beam to a recording medium (not shown). The other light beam produced through the splitting is subjected to

a spatial intensity/phase modulation by a spatial

modulator 112, after which the light beam is further

transmitted via a mirror 113 and converging means 115

to a recording medium (not shown).

5   The light beam emitted from an alignment light

beam source 116 is split into two by means 117 which is

designed to split the alignment light beam, and then,

transmitted via converging means 119 to a recording

medium. The light beam that has been reflected by the

10   reflective layer of recording medium is transmitted to

a position detecting optical system (not shown).

         The means 114 and 115 which are designed to

converge a recording light beam and the means 119 which

is designed to converge an alignment light beam are

15   integrated as indicated by a broken line in FIG. 4.

         When the means for converging a recording light

beam and the means for converging an alignment light

beam are integrated together in this manner, the

relative position of them becomes invariable, thus

20   enabling the alignment of recording/readout light beams

to be performed more accurately.

         Next, this invention will be further explained in

detail with reference to specific examples.

(Preparation of an optical recording medium)

25   First of all, an optical recording medium was

manufactured as explained below.

         Fullerene (C_{70}), the compound represented by

the following chemical formula (1), the compound

represented by the following chemical formula (2) and

polystyrene were mixed at ratios of 0.5:30:10:59.5

(based on weight) and dissolved in toluene to a

5   solution, which was left to stand a whole day and night

in a cooled dark room.

(1)

(2)
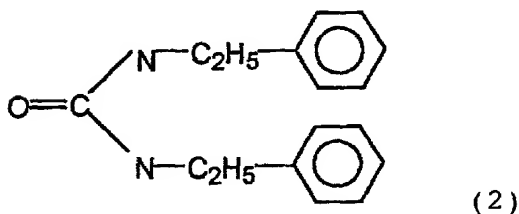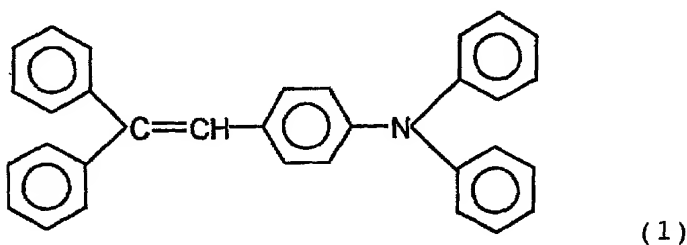
10   On the other hand, a glass substrate having

a recessed/projected surface and a diameter of 5 cm

was prepared. Then, a reflective layer was formed on

this recessed/projected surface, and an ITO (Indium

15   Tin Oxide) film was further deposited thereon.

This reflective layer was featured such that a

recording/readout light beam was permitted to pass

therethrough, but an alignment light beam was reflected

therefrom. For example, the reflective layer was

20   formed of a dielectric multi-layer. The dimension of

the recessed/projected surface were 1000 nm in width

and 150 nm in depth.

On the other hand, another glass substrate having

a flat surface was prepared, and the ITO film was
deposited on the flat surface of the glass substrate.

Then, the aforementioned solution which had been
left to stand was coated on the ITO film of the glass
substrate bearing the reflective layer, and this glass
substrate was heated from the back side thereof at
a temperature of 80℃ for 3 hours by a heater. As a
result, the toluene was allowed to evaporate, thereby
forming a recording layer.

Further, a transparent substrate was heated at
a temperature of 140℃, and then, a spacer having
a thickness of 100 μm was placed on the surface of
the substrate, after which the aforementioned ITO
film-attached glass substrate was superimposed face to
face on the transparent substrate. On this occasion,
the glass substrate was disposed in such a manner that
the ITO film was contacted with the recording layer.
This composite body comprising these transparent
substrates was pressed under a uniform pressure so as
to allow the recording layer to be uniformly extended,
thereby forming a recording layer having a thickness of
100 μm.

Then, for the purpose of effecting the orientation
of molecules, an electric voltage of 1.2 kV was applied
between these transparent substrates at a temperature
of 80℃ and left to stand under this condition for one
hour. Thereafter, while applying an electric field to

these substrates for 30 minutes, this sample was left
to stand, after which the entire body was allowed to
cool down to room temperature.

The construction of the optical recording medium
thus obtained is schematically shown in FIGS. 5A and
5B. FIG. 5A is a plan view thereof, clearly showing
the existence of the recessed/projected reflective
layer 31. In this FIG. 5A, the recessed/projected
portion is shown concentrically. However, the
recessed/projected portion may be spiral in configura-
tion. FIG. 5B is a cross-sectional view thereof,
showing a structure wherein spacers 34 and 38, and
a recording layer 37 are interposed between a glass
substrate 32 bearing an ITO film 33 and a glass
substrate 36 bearing an ITO film 35.
(Construction of information recording apparatus)

The information recording apparatus of the optical
recording medium according to this example will be
explained with reference to FIG. 1.

The light beam emitted from the light beam source
1 is split by beam-splitting means such as the beam
splitter 2, and then, allowed to pass through the
objective lens 11 and 12 as shown in FIG. 1. A spatial
modulator 10 comprising a liquid crystal for giving
a spatial intensity modulation to a light beam is
interposed between the beam splitter 2 and the
objective lens 11. The distance between the objective

lens 11 and the recording region 13 is identical
with the focal length of the objective lens 11.
The distance between the objective lens 12 and the
recording region 13 is 1.5 times as long as the focal

5   length of the objective lens 12. Alternatively, the
objective lens 11, the objective lens 12 and the
optical recording medium 16 may be arranged along the
irradiation path in such a manner the diameter of the
signal light beam and of the reference light beam to

10   be impinged against the optical recording medium 16
becomes 30 μm.

The objective lens 11 and 12 are adjusted in their
directions in such a manner that their optical axes
which have been converged intersect in the recording

15   layer of the optical recording medium 16. Further,
a difference between the length of the optical path of
the light beam emitted from the light beam source and
passing through the objective lens 11 and the length of
the optical path of the light beam passing through the

20   objective lens 12 is shorter than the coherent length
of the light beam source.

The objective lens 14 is adjusted in such a manner
that the light beam that has passed through the optical
recording medium 16 after being converged by the

25   objective lens 11 comes out with an intensity and phase
distribution which is analogous with that of the light
beam entering the objective lens 11. The light beam

that has been turned into a parallel light beam by the
objective lens 14 is detected by a split light beam
detector 15 such as a CCD camera. In this case, the
distance between the objective lens 11 and the spatial

5   modulator 10 is identical with the focal length of the
objective lens 11. Further, the distance between the
objective lens 14 and the split light beam detector 15
should preferably be identical with the focal length
of the objective lens 14. It is also preferable that

10   the distance between the objective lens 11 and the
objective lens 14 is identical with a total of the
focal lengths of these objective lenses.

The optical recording medium 16 is designed to be
driven by a driving device 17, thereby enabling it to

15   be rotated and shifted parallel in a three-dimensional
direction.

On the other hand, the light beam emitted from the
alignment light beam source 21 is passed through a beam
splitter 23, converged at the objective lens 24, and

20   irradiated perpendicularly onto the optical recording
medium 16. This optical recording medium 16 is
provided with a groove to thereby make it possible to
identify in advance the direction of the radius vector.
The surface of the groove is covered with a dielectric

25   multi-layer which permits the permeation of a
recording/readout light beam, but reflects the
alignment light beam.

The light beam reflected by the optical recording medium 16 is permitted again to pass through the objective lens 24, entering from the opposite side thereof this time, after which the light beam is reflected by the beam splitter 23 and transmitted to a tracking optical system and a focusing optical system (not shown). As for these tracking optical system and focusing optical systems, there is not any particular restriction.

Alternatively, by a holographic optical element, an optical system can be easily designed.

By the optical system shown in FIG. 1, the method of irradiating the alignment light beam, the distance between the objective lens 11 and the optical recording medium, and the distance between the objective lens 12 and the optical recording medium were adjusted as follows so as to perform the recording and readout of information.

The alignment means using a holographic optical element will be explained with reference to FIG. 7 and FIG. 8. The light beam emitted from the alignment light beam source 151 is designed to be polarized at 152. As indicated by a reference numeral 153, HOE is designed such that the polarized light beam in the direction of 160 (the same direction as that of 152) is permitted to pass therethrough, and the polarized light beam in the direction of 162 which is perpendicular to

the direction of 160 is diffracted. On this occasion, the light beam emitted from the light beam source 151 is allowed to pass through the HOE, and a $\lambda/4$ plate 154, and to be converged by the objective lens 155

5   before it is finally irradiated onto the optical recording medium 16.

The light beam reflected by the optical recording medium is allowed to pass via the objective lens 155 and the $\lambda/4$ plate 154 to the HOE 153. Since the

10   polarization direction 156 is perpendicular to the direction 152, the light beam is diffracted by the HOE 153 and hence transmitted toward the optical detector 157. The intensity of the beam detected by the optical detector 157 is calculated to determine the focusing

15   signal and tracking signal, whereby the alignment thereof is performed by the driving device 17.

It is assumed in this case that the deviation in a three-dimensional direction between the focus position on which the alignment light beam emitted from

20   the alignment light beam source is converged, and the focus position of the recording/readout light beam is identified in advance. Further, the alignment light beam emitted from the alignment light beam source 21 may be always or intermittently irradiated onto the

25   optical recording medium 16. Whereas, the light beam (signal light beam) emitted from the recording/readout light beam source 1 and permeated through the spatial

modulator 10 should be controlled in such a manner
that it is shielded and hence not irradiated onto the
optical recording medium 16 except on the occasion of
recording information.

5   (Recording of information)

By the information recording apparatus shown in
FIG. 1, a hologram was recorded in the optical
recording medium which was manufactured as mentioned
above.

10   First of all, by the driving device 17, the focus
of the recording/readout light beam was adjusted so as
to position it at an innermost side of the recording
region 13 of the optical recording medium 16.
Thereafter, on the basis of the tracking signal and

15   focusing signal which were obtained from the alignment
optical system, the position of the optical recording
medium 16 was finely adjusted.

After the state of the spatial modulator 10 was
adjusted so as to obtain an intensity distribution of

20   permeating light beam corresponding to the information
to be recorded, the recording light beam was irradiated
for a predetermined period of time. Then, the optical
recording medium 16 was rotated by the driving
device 17 so as to allow the recording light beam to

25   be irradiated at a different recording region.
Subsequently, after the state of the spatial modulator
10 was adjusted so as to conform it with the

information desired to be recorded, the recording light beam was again irradiated for a predetermined period of time.

By repeating the same procedures as described above, data can be successively recorded along the direction of the track.

(Readout of information)

Next, using the information recording apparatus shown in FIG. 1, the readout of information which was recorded in the optical recording medium was performed.

First of all, by the driving device 17, the focus of the objective lens 12 was adjusted so as to position it at an innermost periphery of the recording layer of the optical recording medium 16. Thereafter, on the basis of the tracking signal and focusing signal which were obtained from the alignment optical system, the position of the optical recording medium 16 was finely adjusted.

More precious adjusting of the position in the direction of the track can be carried out as follows. The light beam passing through the objective lens 12 was irradiated onto the optical recording medium 16, thereby adjusting the position of the direction of track. The adjustment of the position of the direction of track can be performed by the procedures described in a publication, "Implementation of Holographic Optical Disc", G. Zhou; A. Pu; O. Ivanova; F. Mok, and

D. Psaltis; Proceeding of the International Symposium
on Optical Memory (pp. 14-15, 1998). As a result, it
was possible to confirm that the readout light beam was
correctly focused.

5   More specifically, a window is positioned outside
the data readout region on the occasion of irradiating
the readout light beam, and when a pit reached this
window, it is considered that the readout light
beam has been correctly focused. By measuring the
10   diffracted readout light beam by the split optical
detector 15 such as CCD, information can be read out
at a high SN ratio.

In particular, as already explained with reference
to FIGS. 2A to 2C, when the optical axis of the light
15   beam that has been converged by the objective lens 11
and 12 is parallel with the direction of track, the
alignment of recording/readout light beam can be
accurately performed.

Further, as already explained with reference to
20   FIG. 3, if the wavelength of alignment light beam is
selected from those at which there is no change in
refractive index of the optical recording medium before
and after the recording of a hologram, the alignment
of a recording/readout light beam can be accurately
25   performed.

Further, in the information recording apparatus
constructed as shown in FIG. 1, a light beam emitted

from the recording light beam source is split into
two beams, i.e. a signal light beam and a reference
light beam. These light beams should preferably be
irradiated onto a three-dimensional optical recording

5   medium at an incident angle which makes it impossible
to generate a first order diffraction of the alignment
beam. Specifically, when the line interconnecting the
center of the objective lens 11 and 12, and the center
of the recording region 13 is assumed to be intersected

10   with the surface of the three-dimensional optical
recording medium 16 at angles of $\theta 1$ and $\theta 2$,
respectively, the following conditions should
preferably be satisfied. If these conditions are
satisfied, it becomes possible to further minimize the

15   noise on the occasion of obtaining the tracking signal
and the focusing signal.

In this case, the refractive index of the
recording layer is represented by n, the wavelength of
light beams emitted from the recording/readout and

20   alignment light beam sources are represented by λ_1 and
λ_2, respectively. The relationship involved in this
case will be explained with reference to FIG. 6.

Although the recording of a hologram is performed
by converging a laser beam before it is irradiated,

25   it is assumed in this case that a parallel light beam
passing through the optical axis is irradiated onto
an optical recording medium. Under this assumption,

the conditions which would not cause the diffraction
of an alignment light beam even if hologram has been
recorded therein will be determined as follows.

A light beam emitted from the recording light beam
5   source is split into two of beams, i.e. a signal light
beam and a reference light beam, and when these light
beams are irradiated to and intersected with each
other in a three-dimensional optical recording medium,
an interference fringe is caused to generate. In this
10   case, when the incident angle of a signal light beam
as measured outside the optical recording medium is
assumed as being $\theta 1$, the incident angle $\theta 1^{in}$ of
a signal light beam as measured inside the optical
recording medium becomes: $n \sin \theta 1^{in} = \sin \theta 1$. In the
15   same manner, since $n \sin \theta 2^{in} = \sin \theta 2$ can be
established for the reference light beam also, the
incident angle as measured inside the optical recording
medium can be determined. The wave number vector of
the interference fringe to be formed in this case can
20   be determined by the following numerical formula (1).

$$\vec{k} = \overrightarrow{k_1} - \overrightarrow{k_2} = \frac{2\pi}{\lambda 1 / n} \begin{pmatrix} \sin \theta 1^{in} - \sin \theta 2^{in} \\ 0 \\ \cos \theta 1^{in} - \cos \theta 2^{in} \end{pmatrix}$$

numerical formula (1)

Under the conditions where the alignment light
25   beam is irradiated perpendicular to the interference
fringe in this manner, the diffraction can be most

strongly generated when the value $\theta 0$ which is capable

of satisfying the following numerical formula (2) is

exists.

$$\frac{\Lambda}{\sin \theta K} + \frac{\Lambda}{\sin \theta 0} = \lambda 2 / n \qquad \text{numerical formula (2)}$$

wherein, $\Lambda = \dfrac{2\pi}{|\vec{k}|}$ is the period of the grating.

Therefore, the condition where a direction which

strongly diffracts the alignment light beam does not

exist will be represented by the following numerical

formula (3).

$$\frac{1}{\sin \theta 0} = \frac{\lambda 2 / n}{\Lambda} - \frac{1}{\sin \theta K}$$

$$= (\frac{\lambda 2}{\lambda 1} - \frac{1}{\cos \theta 2^{in} - \cos \theta 1^{in}})^{*} \sqrt{2 - 2 \cos (\theta 2^{in} - \theta 1^{in})} < 1$$

$$\text{numerical formula (3)}$$

When this condition is met, the alignment light

beam would not be interfered with even if a hologram

is recorded in the medium, thereby making it possible

to greatly minimize the noise to be generated on the

occasion of obtaining a tracking signal and a focusing

signal.

This invention is not limited to the aforemen-

tioned examples or embodiments. For example, the

alignment light beam may be permitted to pass

through the medium, this permeated light beam being

subsequently detected so as to perform the alignment.

Additionally, this invention may be variously modified

without departing from the merit of this invention.

As explained above, it is provided, according to this invention, an information recording medium for recording information in a three-dimensional

5   photorecording medium, the information being recorded in the form of a hologram, which is featured in that the tracking and focusing of a recording light beam can be accurately achieved. It is now possible through the employment of an information recording apparatus of

10   this invention to greatly improve the SN ratio on the occasion of reading data from the three-dimensional photorecording medium, and therefore, this invention will be very valuable from an industrial viewpoint.

Additional advantages and modifications will

15   readily occur to those skilled in the art. Therefore, the invention is its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the

20   spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.